

# Harmonic Minimized of Cascaded H-Bridge Multilevel Inverter Using PV system

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**Abstract**—This paper focusing on the harmonic minimization of 11-level cascaded H-multilevel inverter using PV systems with a Pulse Width Modulation (PWM) control scheme. The photo-voltaic arrays are connected to eleven level multilevel inverter through DC-DC boost converter. By implementing maximum power point tracking (P&O) algorithm are producing power from PV array. The DC power from the PV array is boosted by using the DC-DC boost converter. Which is controlled by PI controller. This methodology of simulation has been carried out and verified through the MAT LAB/SIMULINK to achieve a mitigated Total Harmonic Distortion (THD).

**Keywords**— Cascaded H-bridge multilevel inverter, Maximum Power Point Tracking (MPPT), Photo voltaic (PV), Pulse Width Modulation (PWM)

## 1. INTRODUCTION

The standard of living of any country can be directly related to per capita energy consumption. Energy crisis is due to two main reasons, first is due to lack of energy sources and second is due to lack of efficient energy conversion techniques. But these days, because environmental problems the development and demand for renewable energy has increased. Renewable energy is the energy from natural resources like sun, wind, tides, nuclear and hydroelectric power. The renewable energy is named as eco-friendly and it can replace non-renewable energies like oil and coal. Fuels cells, water, wind, and PV energy are all renewable energy sources. Photovoltaic has no adverse effect caused by tsunami, earthquake, volcanic eruption etc. It is promising clean renewable energy source. It reduces the exhaust of electric energy and realizes the sufficient use of the natural resources.

Power-electronic inverters are becoming popular for industrial drives applications. IGBT's are used as switches in the most of the converter circuits because of high switching frequency. Harmonic current generated in the nonlinear load is remarkable issue, such as added power electronic equipment has come into wide use in industries. Thus the harmonic current causes degradation of power devices and faults in the power system. [1]-[5] This project work is mainly based on using solar energy as source for multilevel inverter to produce stepped sine waveform without losses at reduced harmonic content at load terminals.

## II. MATHEMATICAL MODEL OF THE PV ARRAY

### A. Simplified Equivalent Circuit

A solar cell basically is a p-n semiconductor junction. While visible to light, a current proportional to solar irradiance is generated. The circuit model of PV cell is shown in Fig. 1. Customary simulation tools develop the approximate diode in order to simulate all electric circuits that surround diodes. The model is formed on two-segment piecewise linear estimate. The circuit comprises of  $R_{on}$  in series with voltage source  $V_{on}$ .

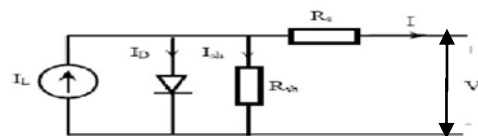


Fig. 1 Circuit model of PV solar cell

### B. Theoretical Mathematical Model

The equation (2) that describe I-V characteristics of the solar cell based on simple equivalent circuit shown in Fig. 1, equations given below;

$$I_D = I_0 \left[ e^{\frac{q(V+IR_s)}{KT}} - 1 \right] \quad (1)$$

$$I = I_L - I_0 \left[ e^{\frac{q(V+IR_s)}{KT}} - 1 \right] - \frac{V+IR_s}{R_{sh}} \quad (2)$$

Where:

I- is the cell current (A).

q-is the charge of electron =  $1.6 \times 10^{-19}$  coulombs

K -is the Boltzman constant (j/K).

T -is the cell temperature (K).

$I_L$ - is the light generated current (A).

$I_0$ - is the diode saturation current.

$R_s, R_{sh}$ -are cell series and shunt resistance (ohms).

V-is the cell output voltage (V).

### C. PV Characteristics

Current Vs Voltage Characteristics: Equation (1) was used in computer simulation to obtain the output characteristics of a solar cell, as shown in the Fig. 2.

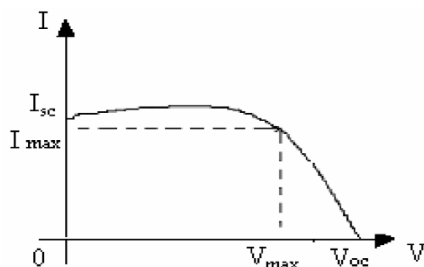


Fig. 2. Output Characteristics of Solar Cell

### D. Power Vs. Voltage Characteristics

The Fig.3 shows the typical Power versus Voltage curve of the PV array. In this Fig:3 P is the power extracted from PV array and V is the voltage across the terminals of the PV array. The characteristics have different slopes at various points. When maximum power is extracted from PV array the system is operating at MPP where slope is zero. The PV curve varies according to the current insolation and temperature. When insolation intensifications, the power available from PV array increases whereas when temperature rises, the power vacant from PV Array decreases.

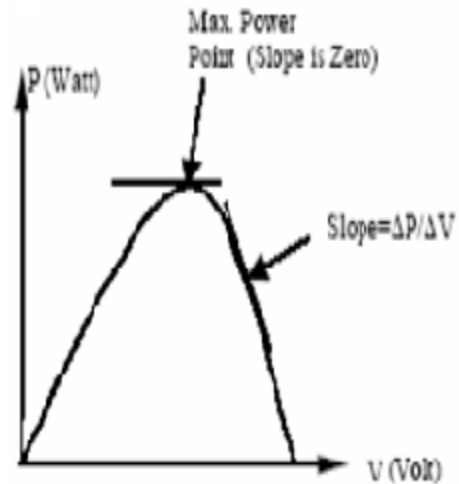


Fig 3: Deviation In Accessible Energy Due Sun's Incident Angle Variation

### E. Variation in Available Energy due to Sun's Incident Angle

PV cell output with respect to sun's angle of incidence is approximated by a cosines function at sun angles from  $0^\circ$  to  $50^\circ$ . Beyond the incident angle of  $50^\circ$  the available solar energy falls off rapidly as shown in the Fig 4. Consequently it is appropriate and sufficient within the normal operating range to model the fluctuations in photocurrent ( $I_{ph}$ ) Vs incident angle is obtained.

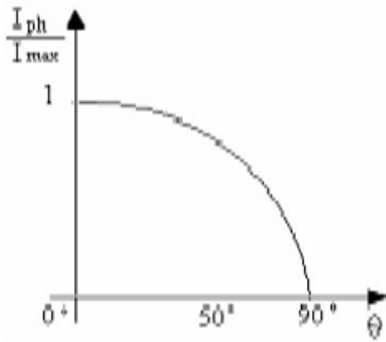


Fig. 4 Variation curve of current with sun altitude

#### F.MPPT Algorithm Method

Tracking the maximum power point of a photovoltaic array is usually an essential part of PV cell. As such many MPP tracking methods have been developed and implemented. The problem considered by MPPT techniques is to automatically find the maximum power output  $P_{Mpp}$  under a given temperature and irradiance

The MPPT methods are:

1. Perturb and Observe (P&O) method
2. Incremental conductance method

TABLE I: Characteristics of Different MPPT Technique

MPPT Technique	Speed	Complexity	Periodic Tuning	Sensed Parameter
Perturb & Observe	Varies	Low	No	Voltage
Incremental Conductance	Varies	Medium	No	Voltage, Current

#### G.MPPT Perturb and Observe Flow Chart

The (P&O) method is generally used because of its simplicity and ease of implementation as its name implies this method works by disturbing the system and observing the impact on the power output PV.

If the operating voltage is distributed in a given direction and that the power increase ( $dP/dV > 0$ ) then

it is clear that the disturbance has moved the operating point toward the MPP. By if the power drops ( $dP/dV < 0$ ) then the disturbance has moved the operating point MPP the algorithm will reverse the direction of subsequent disturbance this algorithm is summarized in flow chart Fig.5.

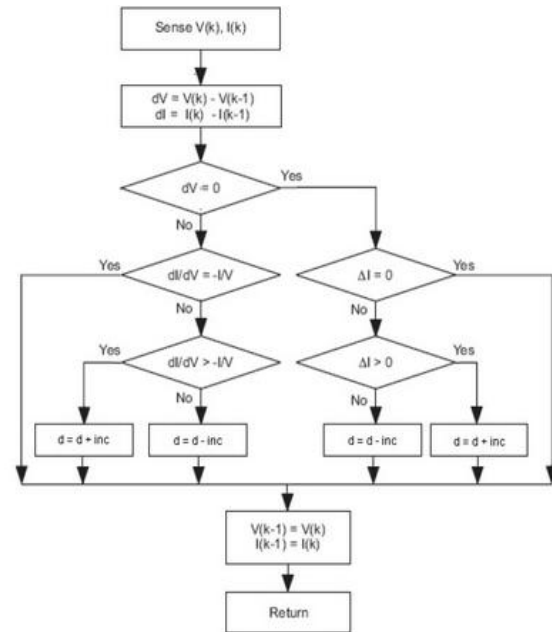


Fig. 5 Flow chart of P&O algorithm

### III.SYSTEM DESCRIPTIONS

#### A. Multilevel Inverter

The concept of multilevel converters has been introduced since 1975. The period multilevel originated with the three-level converter and subsequently, some multilevel converter topologies have been developed. The concept of a multilevel converter is to achieve higher power in which a series of power semiconductor switches with several lower voltage dc sources are arranged to perform the power conversion [6]-[12]. Capacitors, batteries and renewable energy sources can be used as the multiple DC voltage sources. A multilevel converter has several advantages over conventional two-level converter that uses high switching frequency Pulse Width Modulation (PWM).

The input source PV and wind generator is used to maximum power point tracking from the solar panel and wind generator generate the maximum power give the charging battery fed at cascade multilevel inverter. The output voltage waveform of a multilevel inverter is composed of the number of levels typically obtained from eleven levels. As the number of levels reach infinity, the output Total Harmonic Distortion (THD) approaches zero.

Three different major multilevel converter structures have been applied in industrial applications: cascaded H-bridges converter with separate dc sources, diode clamped, and flying capacitors. The term multilevel converter is utilized to refer to a power electronic circuit that could operate in an inverter or rectifier mode. Multilevel converters not only can generate the output voltages with very low distortion, but also can decrease the dv/dt stresses. Thus Electro Magnetic Compatibility (EMC) problems can be reduced.

Multilevel inverters are synthesizing a large number of levels have lot of merits such as improved output waveform, a smaller filter size, lower Electro Magnetic Interference (EMI), and reduced harmonics. There are many control techniques to reduce harmonics in output voltage waveforms. Normally Pulse Width Modulation (PWM) is widely employed to control output of static power inverters.

The reason for using PWM is that they provide voltage and/or current wave shaping customized to the specific needs of the application under consideration. In this work, maximum energy is obtained from the solar cell and wind generator which is then given to a multilevel inverter using PWM technique.

#### B. Cascade H-Bridge Multilevel Inverter

A single-phase structure of an m-level cascaded inverter is illustrated in Fig.6. Each separate dc source (SDCS) is connected to a single-phase full-bridge, or H-bridge, inverter. Each inverter level can generate three different voltage outputs,  $+V_{dc}$ , 0, and  $-V_{dc}$  by connecting the dc source to the ac output by different combinations of the four switches,  $S_1$ ,  $S_2$ ,  $S_3$ , and  $S_4$ .

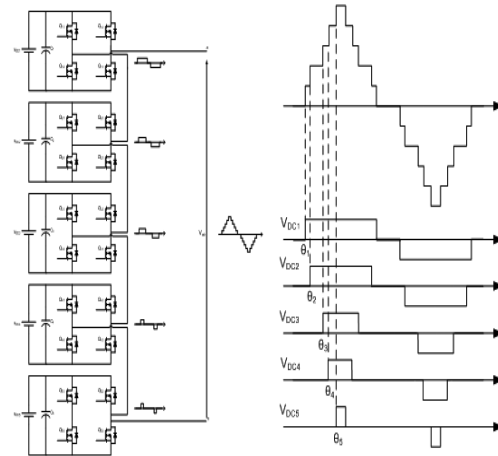


Fig.6 Eleven Level cascaded multilevel inverter and output voltage waveforms

To obtain  $+V_{dc}$ , switches  $S_1$  and  $S_4$  are turned on, whereas  $-V_{dc}$  can be obtained by turning on switches  $S_2$  and  $S_3$ . By turning on  $S_1, S_2, S_3$ , and  $S_4$ , the output voltage is 0. The ac outputs of each of the different full-bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the MLI outputs. The number of output phase voltage levels  $m$  in a cascade inverter is defined by  $m = 2s+1$ , where  $s$  is the number of separate dc sources.

In the 11-level cascaded multilevel inverter with separate DC sources are obtained. The DC sources feeding the multilevel inverter are considered to be varying in time.

## IV. SIMULATION MODEL

### A. Simulation Model of PV System

The simplest model of a PV cell is shown in simulation model Fig.7 Below that consists of an ideal current source in parallel with an ideal diode. The current source represents the generated by photons, and its output is constant under constant temperature and constant incident radiation of light.

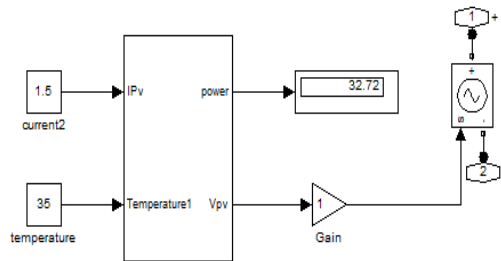


Fig.7 Simulation model of PV cell

### B. Output Voltage of the PV cell

There are two key parameters frequently used to characterize a PV cell shorting together the terminals of the cell, the photon generated current will flow out of the cell as a short-circuit current ( $I_{sc}$ ) therefore,  $I_{ph} = I_{sc}$ ). When around is no connection to the PV cell (open circuit) the photon generated current is shunted internally by the intrinsic p-n junction diode.[13]-[19] This gives the open circuit voltage (V). It is seen that the temperature changes affect mainly the PV output current. The PV cell output voltage is a function of the photocurrent that mainly determined by load current depending on the solar irradiation level.

The output of the PV is shown in Fig.8. The PV output of 29V is obtained by adjusting the values of temperature. The amount of power produced by the PV system depend on the amount of PV radiation the power output can be optimized by choosing a correct system configuration corresponding to a given boost converter.

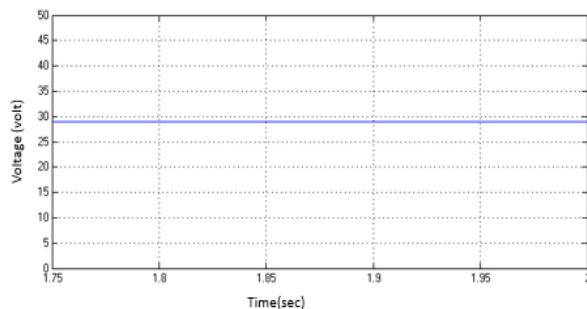


Fig. 8. Output Voltage Waveform of A PV Panel

TABLE II:A.Photovoltaic cell Parameter Values

S.No	Type	Control Parameters
1	Constant	Temperature-35°C Current-1.5A

### C. Simulation Model of MPPT DC/DC Converter

The simulation diagram of the MPPT DC/DC converter is shown in the Fig.9. In case of MPPT algorithms are necessary in PV applications because the MPP of a solar panel varies with the irradiation and temperature, thus the use of MPPT algorithms is required in order to obtain the maximum power from a solar array. The perturb and observe algorithm is used to track the MPPT, as it perform better control under rapidly changing atmospheric condition. So perturb and observe method is used in this proposed method.

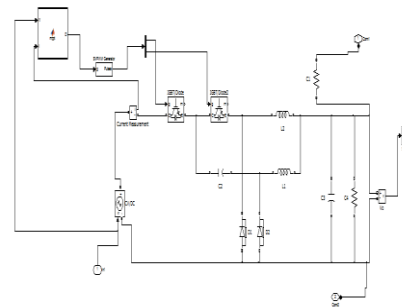


Fig.9. Simulation Model of MPPT DC/DC Converter

### D. Output Voltage Waveform of MPPT DC/DC Converter

The output of the MPPT DC/DC converter is shown in Fig.10. MPPT is used for solar installation system. The output voltage varies with the input voltage. And this MPPT good output regulation. This MPPT is capable of improving the voltage level from 130 V to the required level [20]-[24].

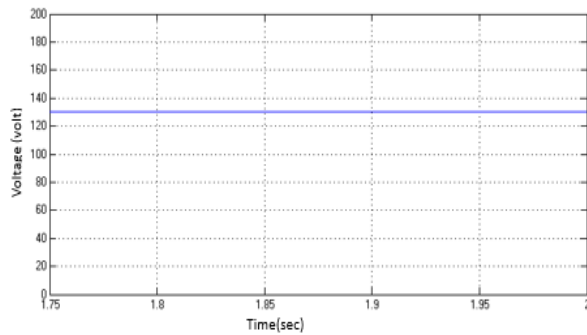


Fig.10. Output Voltage Waveform of MPPT DC/DC Converter

#### E. Simulation Model of PI Controller with PWM Generator

The simulation diagram of the PI controller is shown in the Fig.11. The proportional –Integral controller is output signal every sample time (T), to the control element. The computed from PI algorithm influenced by the controller tuning parameters and the controller error, PI controller have two tuning constraints to modify. While this varieties them more challenging to tune than a P-only controller they are not as complex as the two parameters PI controller hence is used for pulse width modulation technique.

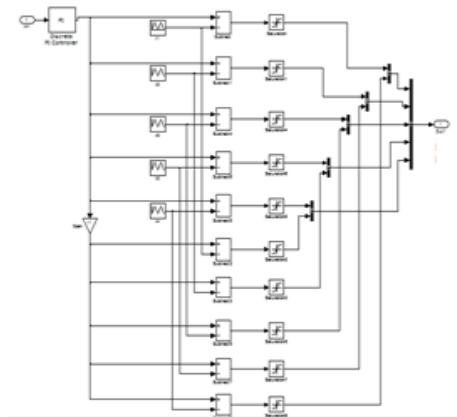


Fig. 11. Simulation Model of PI controller with PWM Generator

In control model, a controller is a device, feasibly in the form of a chip, analogue electronics, or computer, which monitors and physically alters the operating conditions of a given dynamical system.

The step response reveals how the controlled variable reacts to a change in the manipulated variable.[8] This is determined by measuring the controlled variable after a step change in the manipulated variable.

$$K_p \Delta + K_i \int \Delta dt \quad (3)$$

where  $\Delta$  is the error or deviation of actual measured value (PV) from the setpoint (SP).

$$\Delta = SP - PV \quad (4)$$

A PI controller can be demonstrated easily in software such as Simulink or Xcos using a "flow

$$C = \frac{G(1 + \tau s)}{\tau s} \quad (5)$$

Where ,G=  $k_p$  =proportional gain

$$\frac{G}{\tau} = k_i = \text{integral gain} \quad (6)$$

#### F. Simulation Model of 11-Level Cascaded H-Bridge Multilevel Inverter

The eleven- level multilevel inverter has been developed by using MAT LAB is shown in Fig.12 To operate cascaded multilevel inverter using a solar source.[25]-[29] Considering a cascaded multilevel inverter with five H-bridges and the eleven level stepped output voltage is obtained.

Simulation model of eleven level cascade multilevel inverter modulation scheme are pulse width modulation technique is obtained. It consists of PWM generator block has parameters such as amplitude, pulse width period and phase delay which are used to determine the shape of the outputare obtained.



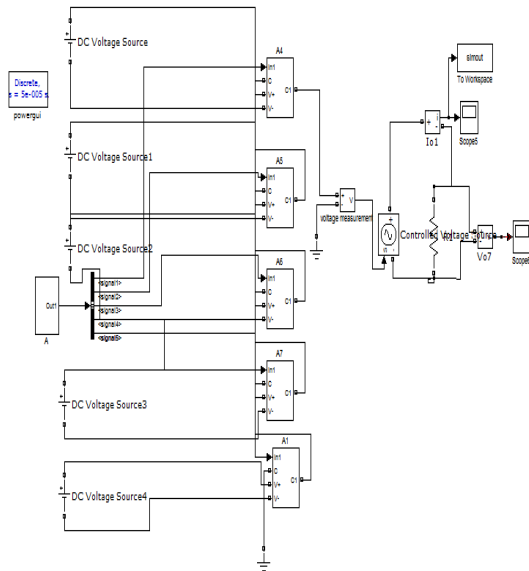


Fig.12. Simulation Model of 11-Level Cascaded H-Bridge Multilevel Inverter

#### F. Proposed Overall Simulation Diagram

The simulation model is shown in Figure.13. The eleven level cascade H-bridge multilevel inverter powered by PV system has been developed by using MAT LAB with the use of this proposed method sinusoidal stepped output waveform is obtained and the harmonics are reduced. Therefore the efficiency of the inverter is increased. Fundamental harmonics are also significantly reduced.[11-13] A key component in this project is the DC to AC eleven level multilevel inverter. The inverter must perform reliably and efficiently to supply a wide range of ac loads with the voltage and required power quality necessary for reliable and efficient load and system performance. With PWM

generator are used in control of eleven level cascade H-bridge multilevel inverter and boost converter. The advantages of the system is high power high voltage capacity, low harmonics and low switching loss.

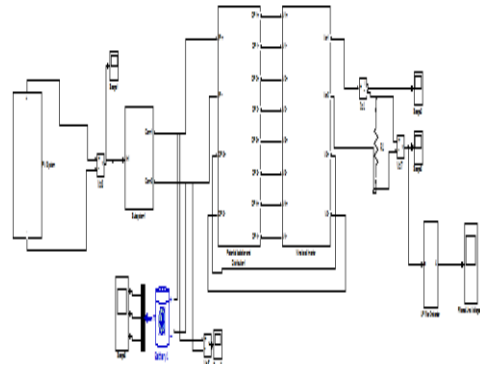


Fig.13. Overall Simulation Diagram

The output of cascade H-bridge eleven level

Name of the topology	Voltage level on each stage	Number of the output level	Number of switches used
Cascade H-bridge multilevel inverter	S.Vdc	2S+1	4S

multilevel inverter is shown in Figure.14 and 15. The output voltage and output current has eleven levels. It can be achieved by using selection switching pattern method. In Figure shown below waveform is obtained is voltage and current Vs time. The output eleven level multilevel inverter fundamental frequency is 50 HZ

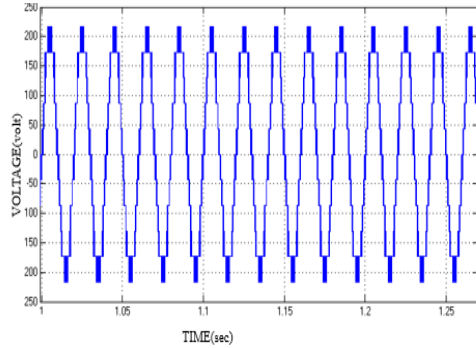


Fig.14. Output Voltage Waveform of Cascade Multilevel Inverter

The loads connected across the cascaded H-bridge multilevel inverter. Due to the parallel connection, voltage 230 V is shown in Fig.14 remains constant for all the resistive loads. But current varies as per the connected load.

In the Figure.15. The output current of cascaded H-bridge multilevel inverter is (2.3Amp) for resistive load ( $R_L=10K\Omega$ ) at constant 230 voltage.

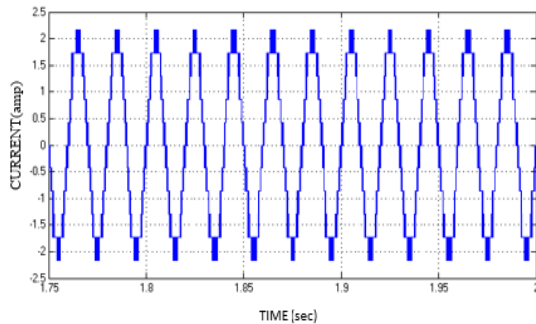


Fig.15. Output Current Waveform of Cascade Multilevel Inverter for  $R_L$  Load

The detailed function of the various blocks used in the system was understood with this knowledge the same system can be modeled with the help of MATLAB software tool and its respective output waveforms of individual blocks used in the proposed system is discussed in detail. It also includes the THD analysis.

THD is the summation of all harmonic components of the voltage or current waveform

#### G.Spectrum Analysis of Total Harmonic Distortion

The Total Harmonic Distortion (THD), of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the essential frequency. THD is used to illustrate the linearity of audio systems and the power quality of electric power systems. The RMS voltage for  $(2p+1)$  levels is,

$$V_{o,RMS} = \sqrt{p^2 - \frac{2}{\pi} \sum_{i=0}^{p-1} (2i+1) \alpha_{i+1}} \quad (7)$$

Where  $p$  is the number of switching angles in half cycle. The Fourier coefficients are,

$$b_n = \sum_{i=1}^p \frac{2}{\pi} \int_{\alpha_i}^{\pi-\alpha_i} E \sin(n\theta) d\theta \quad (8)$$

$$b_n = \frac{4E}{n\pi} \sum_{i=1,3,5,\dots}^p \cos(n\alpha_i) \quad (9)$$

$$THD = \frac{\sqrt{\frac{\pi^2 p^2}{8} - \frac{\pi}{4} \sum_{i=0}^{p-1} (2i+1) \alpha_{i+1} - \left( \sum_{i=1}^p \cos(\alpha_i) \right)^2}}{\sum_{i=1}^p \cos(\alpha_i)} \quad (10)$$

One of the most used techniques for finding the switching angles is to use the Fourier coefficients to eliminate some harmonics [30]. The number of harmonics to be eliminated is equal to the number of switching angles are obtained.

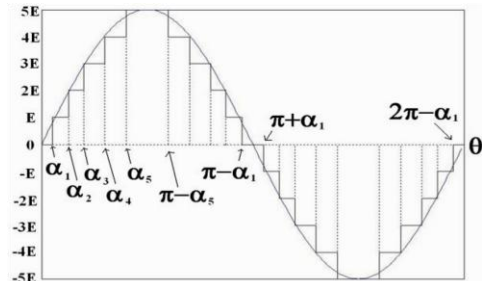


Fig.16 Multilevel inverter with eleven steps

compared against the fundamental component of the voltage or current wave. The eleven level output



voltage 230 V and fundamental frequency is 50 HZ. with THD is reduced. The cascaded H-bridgemultilevel inverter Total Harmonics Distortion is shown in Fig.17. The THD of eleven level multilevel inverter is 2.62%.

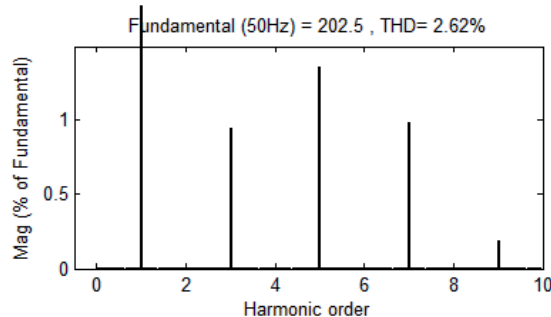


Fig.17 Spectrum Analysis of Total Harmonic Distortion

## V.CONCLUSION

A single phase photo voltaic powered eleven level cascaded H-Bridge multilevel inverter has been proposed. The paper has presented a PWM switching scheme for the proposed multilevel inverter it utilize reference signals and a triangular carrier signal to generate PWM switching signals. As per the design of the proposed 11-level multilevel inverter, the total harmonics distortion is dramatically reduced to 2.62%.

This will be implemented controls to maintain the magnitude and fundamental voltage and PI technique controller in this proposed model the THD can still be minimized.

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